Title: Resilience in Infrastructure Systems

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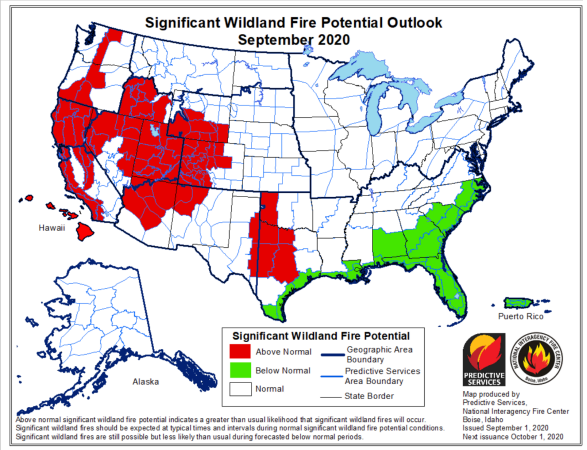
Resilience in Infrastructure Systems

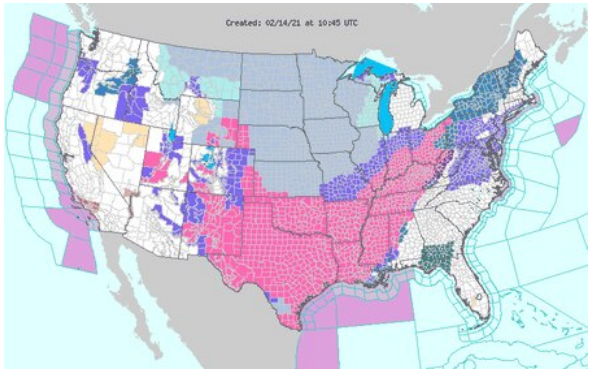
David M Fobes

March 15, 2021

Threats to US Energy Infrastructure

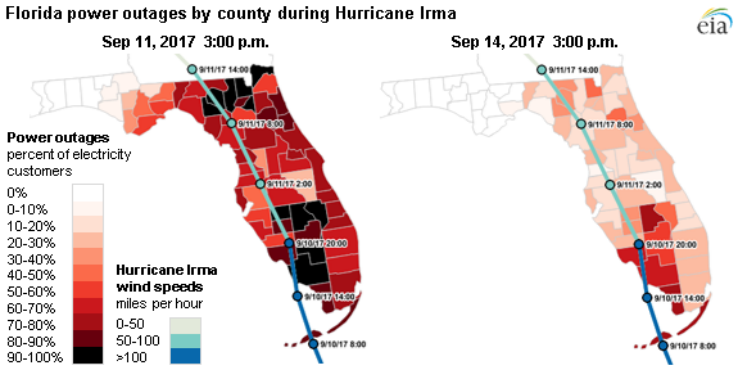
Wildfires

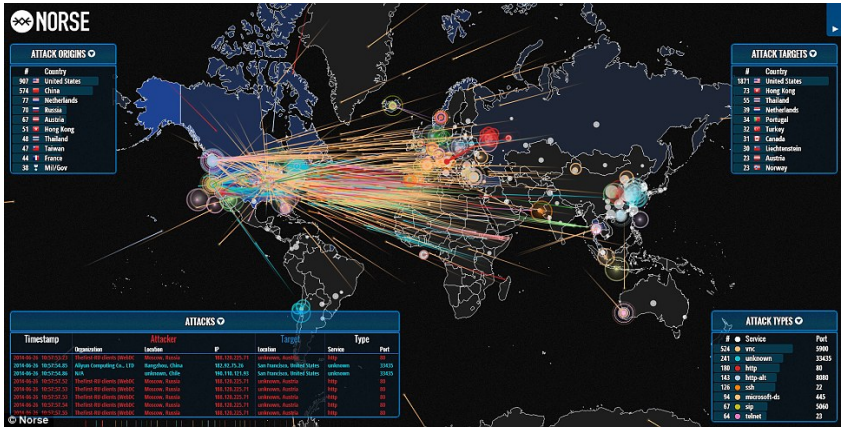




Winter Storms

Hurricanes





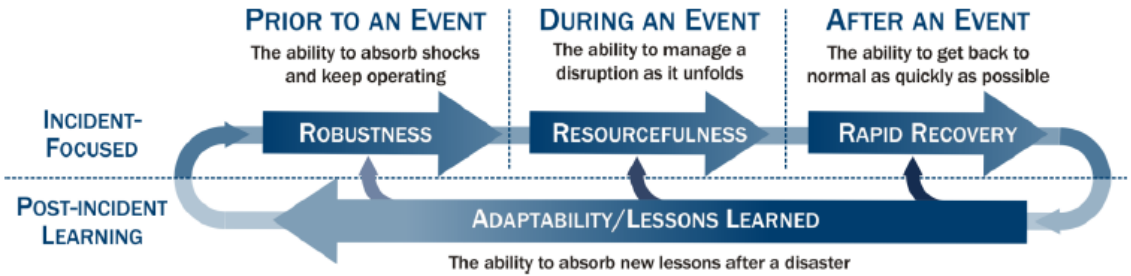
Cyber Attacks

Resilience Against Extreme Events in Energy Systems

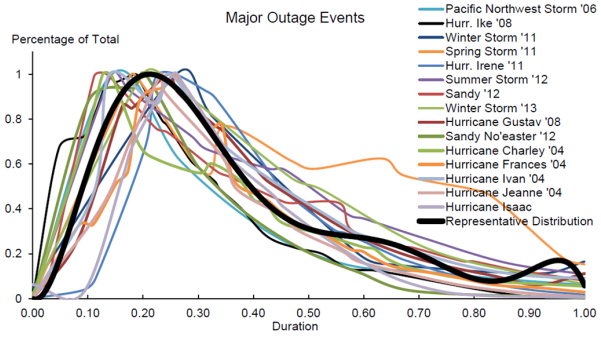
Presidential Policy Directive 21 (Feb. 2013) - Critical Infrastructure Security and Resilience:

"The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."

Exhibit 2.1 The Sequence of the NIAC Resilience Construct



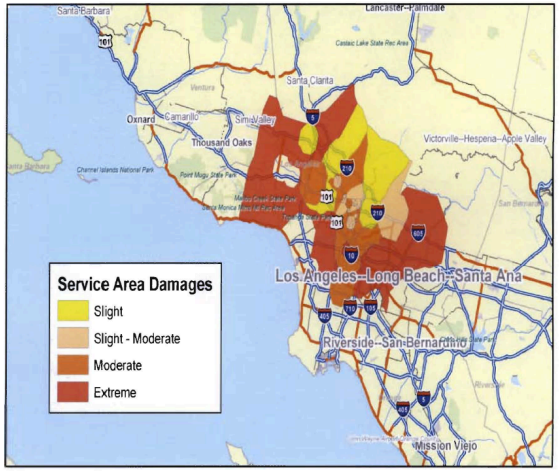
National Infrastructure Advisory Council, "A Framework for Establishing Critical Infrastructure Resilience Goals", 2010.

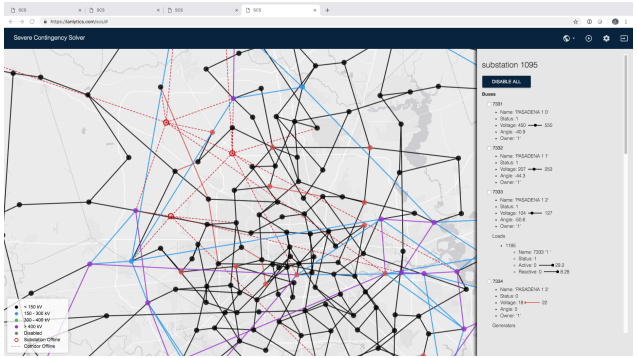


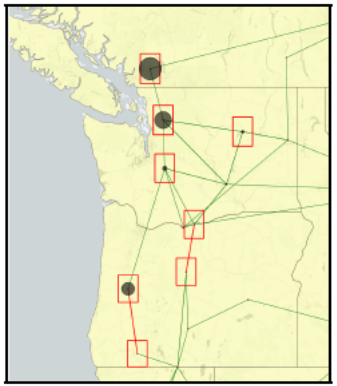
Source: Department of Energy, Office of Electrcity Delivery and Energy Reliability

Achieving Resilience Through Infrastructure Modeling

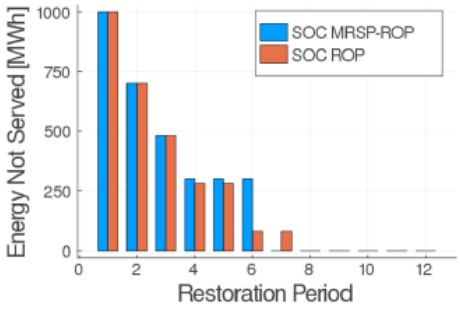
- Predict potential contingencies
- Optimize operator response under contingencies
- Evaluate resilience under a large number of potential contingencies
- Optimize design for resilience
- Explore interdependency between infrastructures



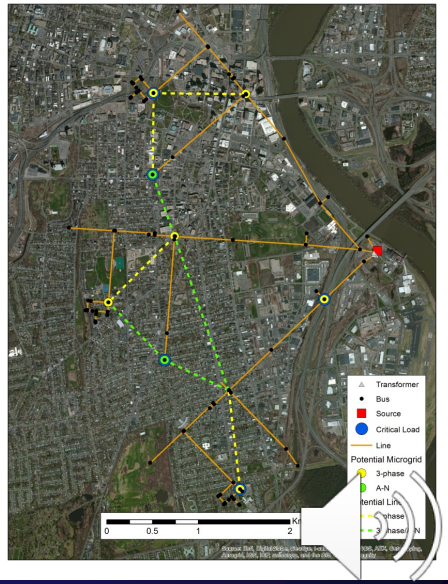




(b) Load shed = 273.68 p.u



(b) 5-bus with MRSP preprocessing.



Building High Technology Readiness Level (TRL) Products

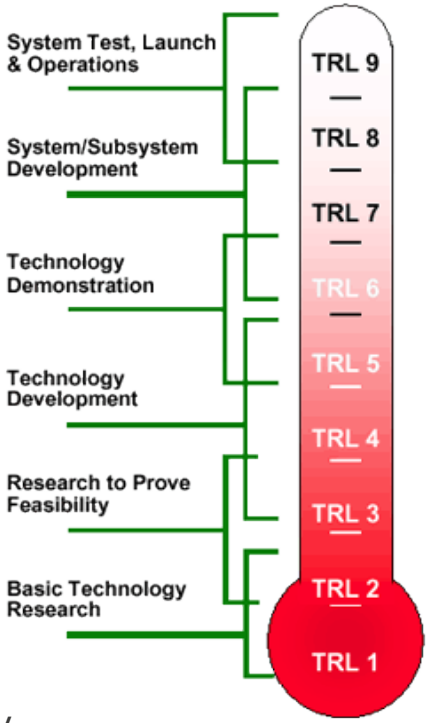
Industry Standard Practices

- Life Cycle Development Plans
- Best Practices Documentation

- Specification and Design Processes
  - Formal API specification
  - Scoping exercises
  - RFC processes

- Agile / Scrum Development Processes
  - Continuous Integration
  - Code Reviews
  - Testing using Industry and Synthetic

- Release Processes
  - Continuous Deployment
  - Semantic Versioning
  - Automated Docker or binary builds for easy integration



Critical Interactions

- Lab Partnerships
- Industry Partnerships and Engagement
- Academic Partnerships
- Stakeholder Engagement

CleanStart Distributed Energy Resource Management System (DERMS) Project Summary

LLNL/LANL/PNNL/Smarter Grid Solutions + Utility Partners

Challenge

What extent of additional services of an isolated distribution feeder, can we black-start with existing DER?

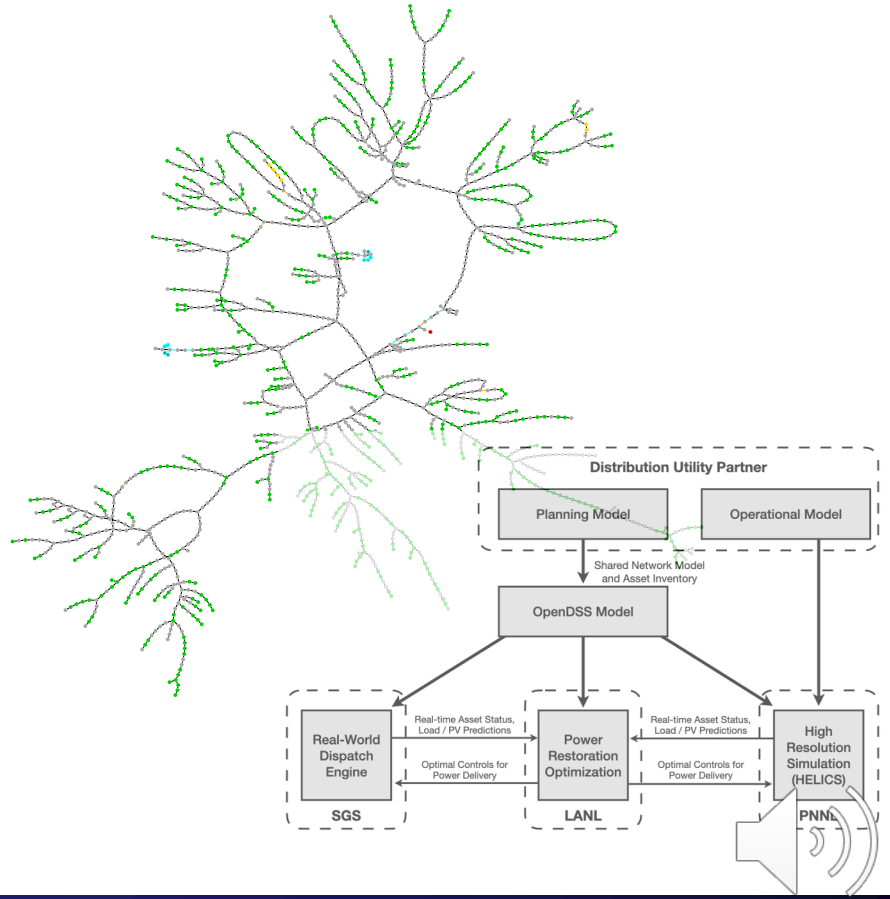
Technical Approach

Use high-fidelity physics-based optimization to find a restoration sequence from blackout conditions which:

(a) Respects the engineering constraints
(b) Prioritizes critical loads
(c) Assumes the feeder is undamaged by the event

Restoration Objective

Restore the maximum possible load as quickly as possible in a given time horizon

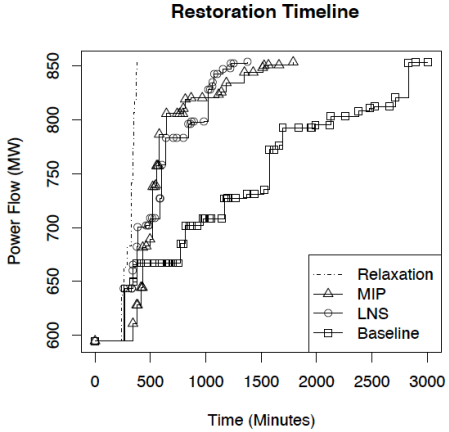


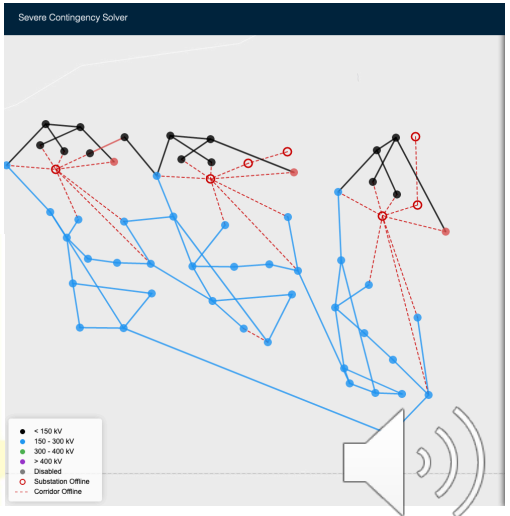
CleanStart DERMS
Foundational Technologies and Investments

- Restoration planning research – DHS NISAC
  - C. Coffrin, P. Van Hentenryck, R. Bent, “Last-mile restoration for multiple interdependent infrastructures”, AAAI 12 (2012), pp. 455-463
  - P. Van Hentenryck, C. Coffrin, R. Bent, et al., ”Vehicle routing for last mile of power system restoration”, PSCC11 (2011)

- PowerModels.jl – DOE AGM & LANL LDRD
  - Created as a response to a large number of new power flow formulations and problem types
  - The first of our high-TRL transmission level optimization tools

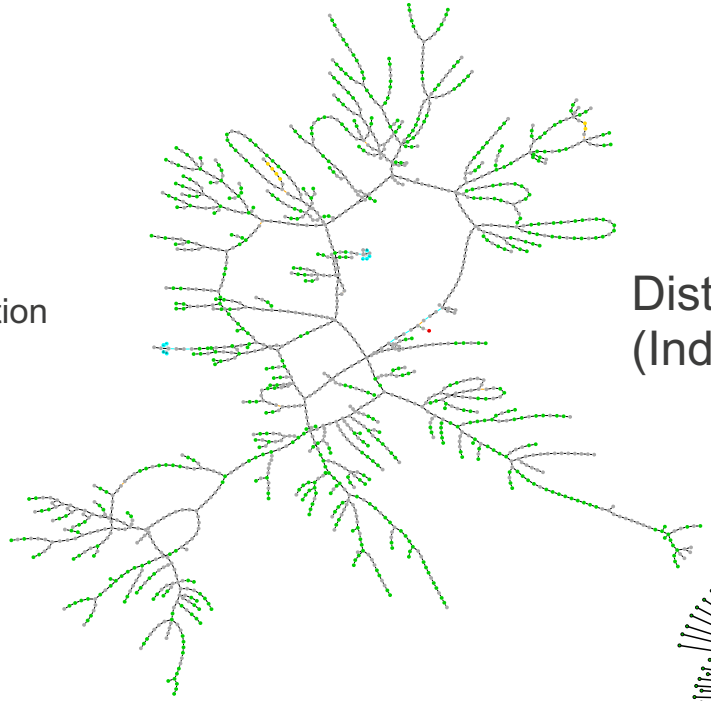
- Multiple Contingency Solver (formerly Severe Contingency Solver) – DHS NISAC
  - autonomously sheds loads, redispatches generators, and reconfigures networks to produce AC feasible power flow solutions in the presence of multiple severe contingencies
  - Used to quantify infrastructure vulnerabilities under extreme events, in particular in the context of seasonal hurricanes



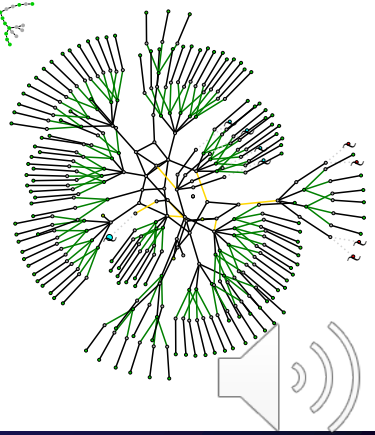


CleanStart DERMS
Key LANL Outcomes

- Publications
  - "A Flexible Storage Model for Power Network Optimization"
  - "PowerModelsDistribution.jl: An open-source framework for exploring distribution power flow formulations" – PSCC 2020
  - "PowerModelsRestoration.jl: An open-source framework for exploring power network restoration algorithms" – PSCC 2020
- Free and Open-Source Software
  - PowerModelsDistribution.jl
  - PowerModelsRestoration.jl
  - PowerModelsAnalytics.jl
- Demonstrations
  - Industry Distribution Feeder Dataset
  - PNNL Sub-Transmission Dataset
- Deployments
  - PNNLs HELICS co-simulation
  - SGS Platform



Distribution Feeder
(Industry dataset)



Sub-transmission network
(Synthetic dataset)

Resilient Operation of Networked Microgrids (RONM) Project Summary

LANL/NREL/Sandia/NRECA + Utility Partners

Objective

Improve the resiliency of power systems with optimization-based methods that leverage advanced microgrid technologies to reduce system recovery times after extreme event induced outages

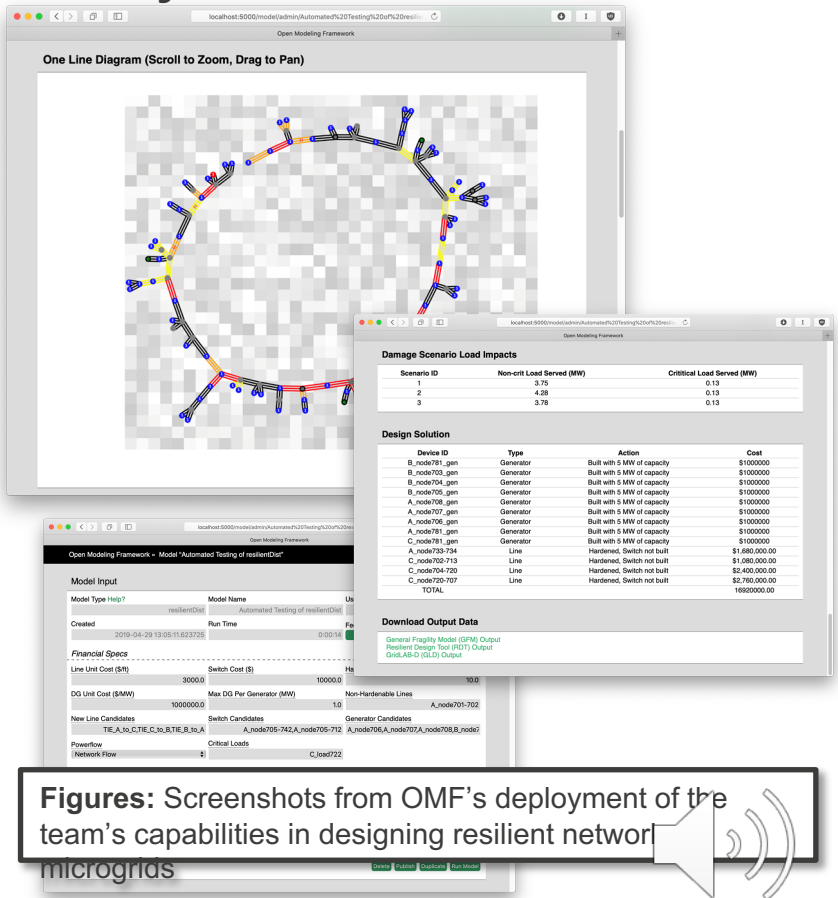
Goal

High-TRL Optimal Operations Tool featuring:

- Protection settings and analysis
- Small signal stability analysis
- Generation dispatch actions
- Load shedding
- Switching actions
- Interactive design tools
- Front-end visualization / GUI

Validation

Evaluate and validate the viability of RONM solutions on practical distribution networks modeled within advanced HIL evaluation platforms.



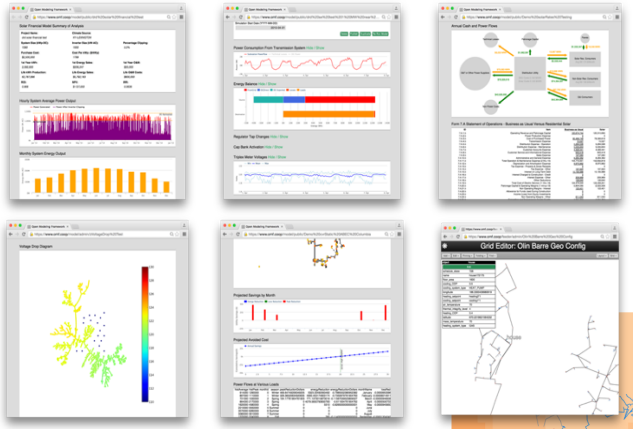
Figures: Screenshots from OMF's deployment of the team's capabilities in designing resilient networ microgrids

Resilient Operation of Networked Microgrids (RONM) Enabling Technologies

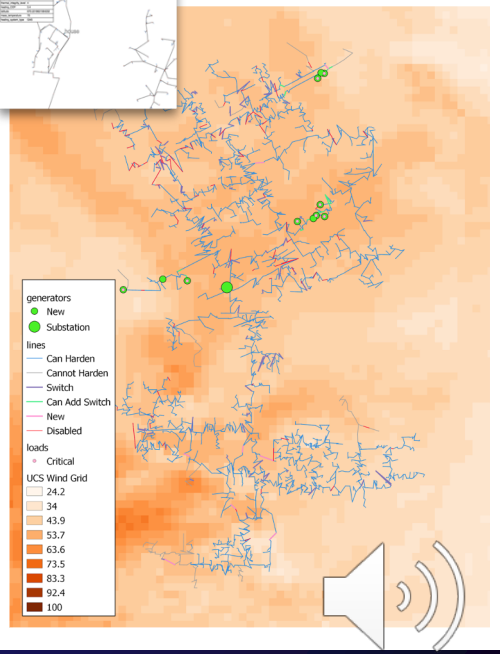
- **RDT** (Resilient Distribution Tool)
  - 2014-2016, small pilot program to build a new capability for the microgrid program
  - Goal: optimize the design of distribution feeders to leverage DER and improve resilience

- **LPNORM**
  - 2016-2019, follow-on GMLC project
  - Goal: transition the RDT capability into a production tool (NRECA's OMF tool)
    - Continues to be used by NRECA for critical infrastructure projects

- **CleanStart DERMS**
  - On-going GMLC project
  - Goal: black-start restoration of distribution feeders



OMF Tool



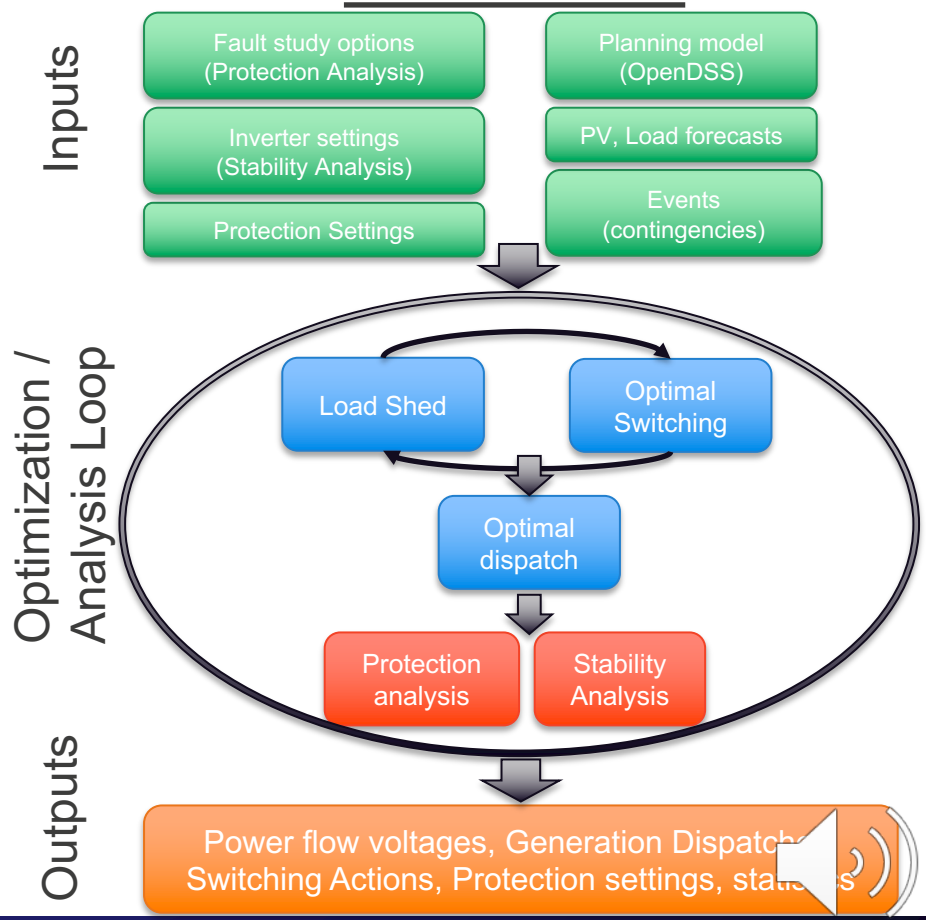
UCS Beta Demonstration

Resilient Operation of Networked Microgrids (RONM)

Key LANL Outcomes

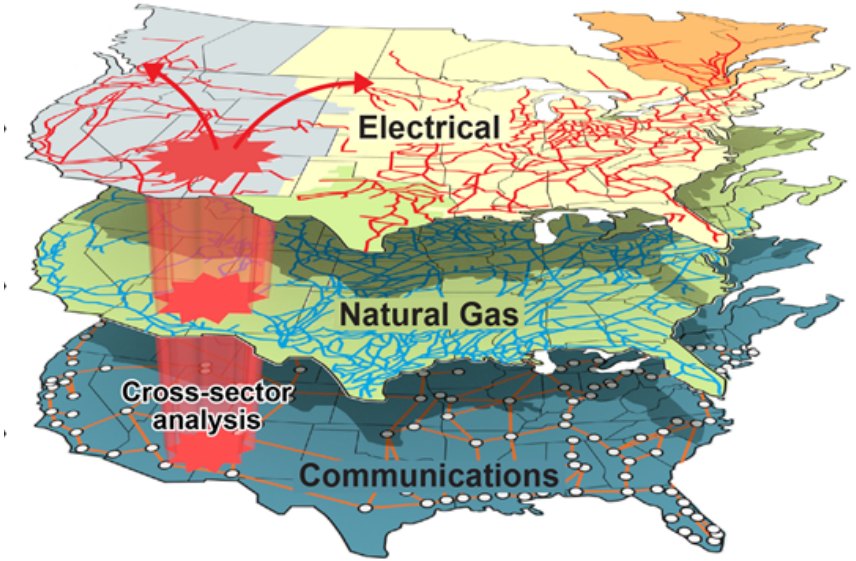
- **PowerModelsDistribution.jl v0.10.3**
  - Models power flows and network operations (DER dispatch, network reconfiguration)
- **PowerModelsProtection.jl v0.2.0**
  - Software extensions for modeling protection and its interactions with fault currents
- **PowerModelsStability.jl v0.1.0-beta**
  - Software extensions for modeling stability constraints
- **PowerModelsRestoration.jl v0.5.0**
  - Algorithms for restoring power systems
- **PowerModelsONM.jl v0.3.4**
  - Integration package

ONM Workflow



North American Energy Resilience Model (NAERM) Summary

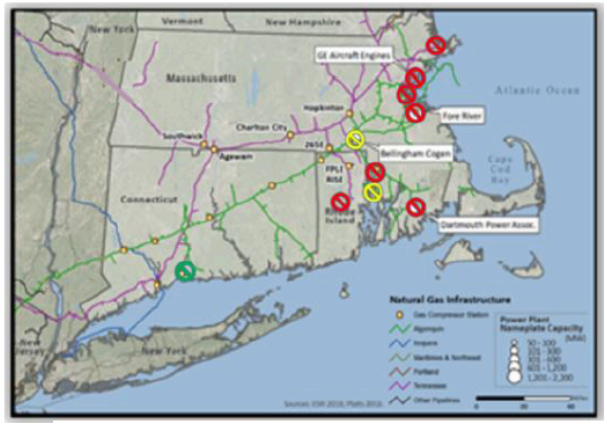
Multi-lab Partnership - NG efforts: LANL/ANL



"North American Energy Resilience Model (NAERM) Status Update", G. Bindewald, G. Yuan

"The energy subsectors are more tightly coupled than ever, with local impacts cascading into other regions and sectors across the Nation."

"The ultimate goal of the project is to provide real-time situational awareness and analysis capabilities for emergency events and optimal operations and recovery, enabling the federal government and industry to quickly and effectively prepare and respond."



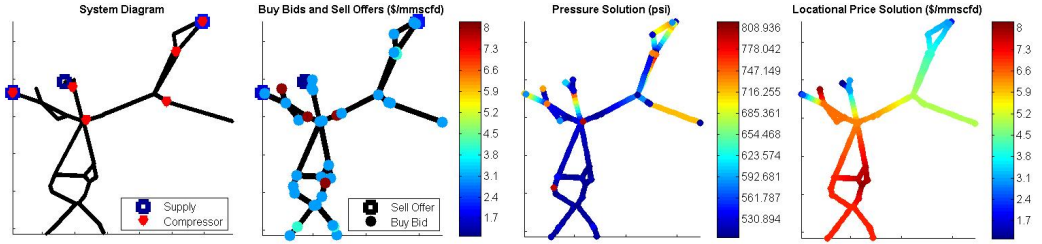
Identification of impacts to gas-fired generators

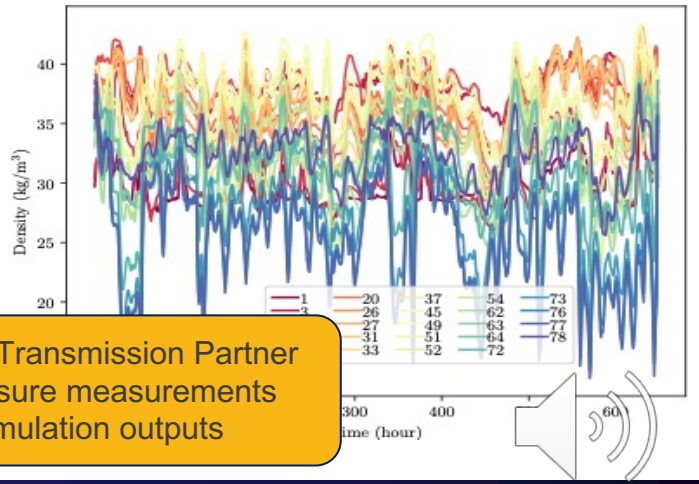
"North American Energy Resilience Model", Report, July 2019

North American Energy Resilience Model (NAERM) Enabling Technologies

- GasModels.jl
  - Steady state modeling for long term planning
  - AGM: “Joint Power System and Natural Gas Pipeline Optimal Expansion Planning”
- Grail (Gas Reliability Analysis Integrated Library)
  - Transient modeling for control market modeling and simulation
  - AGM: “Dynamical Modeling, Estimation, and Optimal Control of Electrical Grid-Natural Gas Transmission Systems”
  - OE Transmission Reliability Program

Field Application with Newton Energy Group: Market-based, gas-electric coordination models which incorporate limits on information exchanged between the infrastructure operators.





Validation Study with Transmission Partner – Comparison of pressure measurements (SCADA data) with simulation outputs

North American Energy Resilience Model (NAERM) Key LANL Outcomes

- GasModels.jl v0.8.2
  - Transient optimal gas flow modeling of single pipeline systems
- GasModelsMultiPipeline.jl v0.1.0
  - Extension of GasModels.jl to model transient optimal gas flows of multiple connected pipelines
- TransientGas Federate v0.7.3
  - Combines the capabilities of LANL's GasModels tools and ANL's NGTransient to multi-infrastructure co-simulations in NAERM (two-way communication with the Bulk Electric System (BES))
- New Open and OUO Transient Models of real-world pipelines
  - Developed a new database and API to store, maintain, and quickly dynamically build new multi-pipeline models based on areas of interest
  - Kern, Questar, EPNG, SoCalGas (LANL); Transco, Maritimes, Algonquin (ANL)

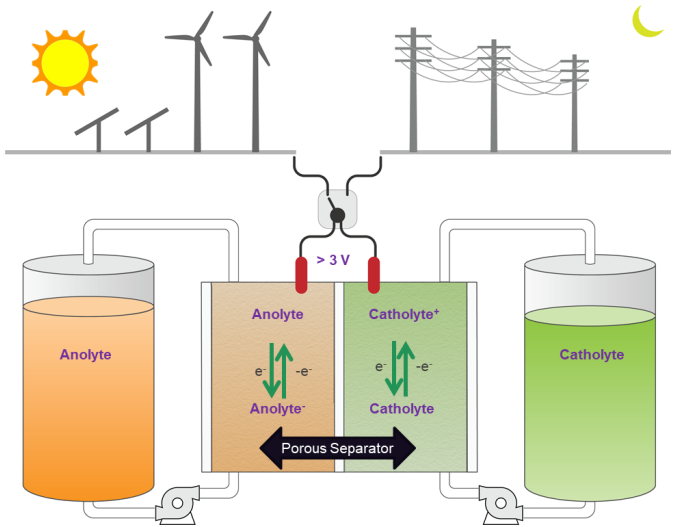
NAERM Visualization Tool

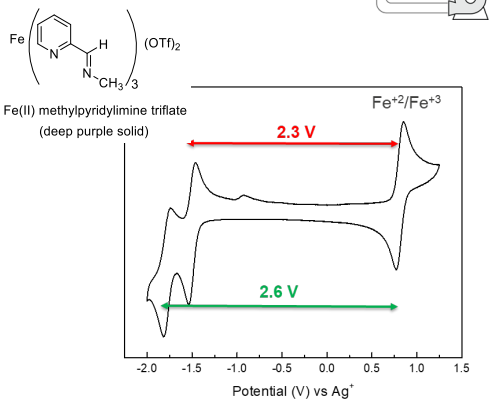
Kern River (HIFLD Open)

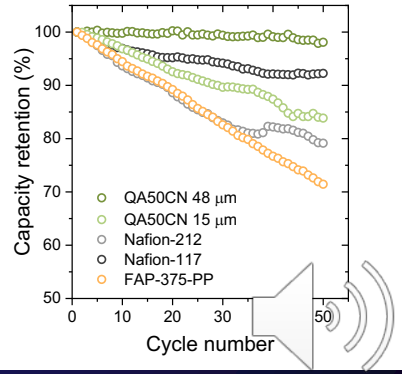
Non-aqueous Flow Battery (NARFB) Development Project Summary

Overview

- Need for a low-cost, durable, energy storage technologies
  - Support integration of renewable energy
  - Resilience support
- Existing technologies have limitations
  - Example: Vanadium-based aqueous flow battery (VRFB) systems are limited by the expense of the Vanadium metal
- LANL solution
  - Lower-cost flow battery technologies based on iron or organic compounds
  - An Iron Pyridylimine system shows potential







Funding: Office of Electricity -Energy Storage Program. Dr. Imre Gyuk

Tools for resilient operations and design in the future

- ”Real-time” resilience analysis
  - By utilizing faster relaxations and approximations it becomes possible to spot potential problems before they arise, and to react more efficiently once they do, e.g., by performing forensic fault analysis to optimally isolate a fault and continue operations to the largest number of customers, or to perform stability analysis on borderline switching actions to evaluate risk-vs-reward.

- Increasing renewable resource penetration
  - Optimization tools for resilient design can enable utilities to utilize their budgets in the most efficient way possible by helping to identify correctly sized DERs for various applications and scenarios, which will help to achieve higher penetration of renewable resources faster.

- Reducing the grid’s carbon footprint while maintaining resilience
  - Although there is a long-term shift towards renewable energy sources, fossil fuels are likely to have a long tail, continuing to have an important role in generation and critical service support. With optimization tools, there is the potential to reduce day-to-day dependencies on legacy fuels, while maintaining adequate safety margins to maintain services during extreme events.